Electrostatic LEBTs for High-Intensity Linac-Injectors *

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Abstract. This paper discusses options for Low-Energy Beam Transport (LEBT) systems as part of injectors for high-intensity linear accelerators such as proton drivers and similar machines. Building on the demonstrated success of the Spallation Neutron Source (SNS) front end, the presented LEBT designs are based on the electrostatic focusing principle, but the arrangement of lenses and steerer elements is modified for ease of operation and to reduce optical aberrations that somewhat affected the performance of the SNS LEBT. After treating two examples of such LEBTs to be applied to proton and deuteron beams, an extraction system for H^- beams is presented that provides for electron removal at intermediate energy and can easily be integrated into an electrostatic LEBT of the type discussed before. Beam simulation results with output emittances for the three systems are included in the paper.

Keywords: Proton driver injector, low-energy beam transport, electrostatic
PACS: 29.25.Ni

INTRODUCTION

The Front End (Linac Injector) for the Spallation Neutron Source (SNS) has clearly demonstrated the general feasibility of using electrostatic Low-Energy Beam Transport (LEBT) systems with high-intensity H^- ion beams [1]. A layout of this LEBT is shown in Fig. 1, measured and simulated emittances in Fig. 2.

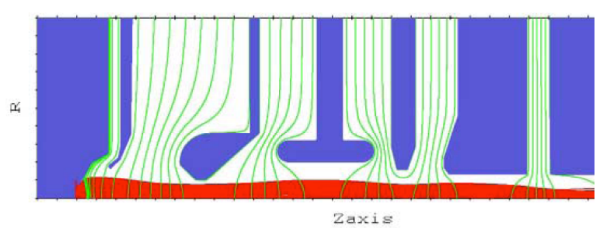

FIGURE 1. SNS Front-End LEBT for a 45-mA H^- beam (half section, tick marks represent 1 cm). The electrode potentials are, from left to right, 65, 60, 0, 45, 0, 43, and 0 kV.

The 60-kV electrode in this LEBT intercepts most of the electrons extracted together with the negative ions; the electrons are deflected by a strong magnetic dipole field positioned across the aperture of the 65-kV outlet electrode. The ion source and the first two LEBT electrodes have to be tilted by 3 degrees with respect to the main LEBT axis to compensate for the kick received by the H- ions. The second lens, at 43 kV potential, is split into four quadrants, and additional steerer voltages and chopping waveforms are superimposed on the common static potential.

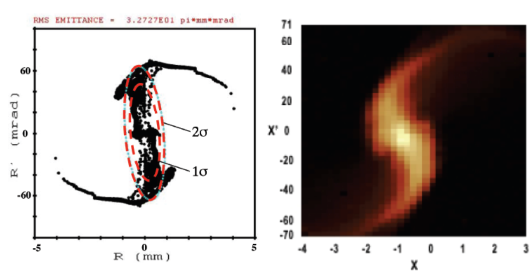

FIGURE 2. Simulated r/r’ emittance [2], left, and measured horizontal emittance [3] for the LEBT beam shown in Fig. 1. Effects of aberrations are evident.

Building on these experiences, a family of improved, electrostatic LEBTs was designed for a variety of applications involving positive or negative ions. As with the earlier SNS design, these LEBTs contain two electrostatic lenses as main elements, but now the lenses are much wider than the beams which therefore suffer much less from optical aberrations, and the electrostatic two-axis steerer system is placed on ground potential in the space between the two lenses, eliminating the need for splitting the second lens into quad-

* This work supported by Office of Basic Energy Sciences, U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

rants and reducing the effects of sparks. These LEBT structures would match the beam into a subsequent accelerator structure, typically an RFQ accelerator requiring an envelope convergence angle of about 50 mrad in both transverse planes. Modeling of the beam formation and transport processes is performed by using the code PBGUNS [4] with its options for positive and negative ion beams, respectively, generally assuming cylindrical symmetry of the problem.

NEW LEBT LAYOUTS FOR POSITIVE IONS

The first of the new LEBT structures, see Figures 3 and 4, will accommodate a 15-mA, 80-keV deuteron beam extracted from a 2.45-GHz ECR ion source and designated to be utilized in a 5-MeV Accelerator-Driven Neutron Source for a cargo screening application [5].

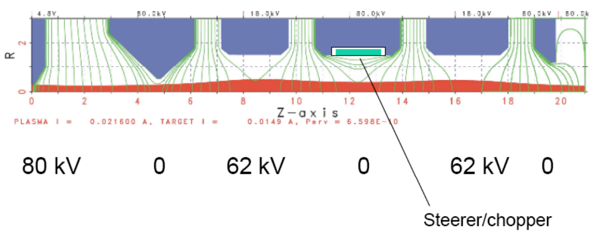

FIGURE 3. 15-mA deuteron LEBT (half section, distances given in cm).

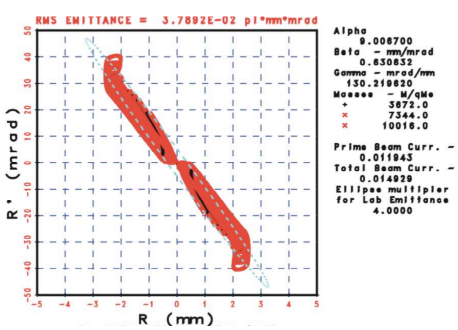

FIGURE 4. Simulated r/r' emittance of 0.038 π mm mrad rms size, for the LEBT shown in Fig. 3. Only minimal signs of aberration effects are visible. The simulation takes into account the 875-G axial magnetic field of the ECR plasma generator that extends into the extraction gap.

Electrostatic steerer voltages, and possibly chopper waveforms, are applied to the steerer plates from ground potential, making the associated power supplies and electronic switches inherently safer to operate. These plates are also well screened from the high voltages applied between ground and the adjacent lens center electrodes, again enhancing the operational reliability of the system.

A similar LEBT layout has been modeled for a 113-mA, 100-keV proton beam, suitable for injection into an RFQ that could serve a generic Proton Driver Linac. The chosen beam current value would be equivalent in space-charge action to a 90-mA H^- beam together with about 10 times as many electrons. Mechanical layout and simulated emittance are shown in Figures 5 and 6.

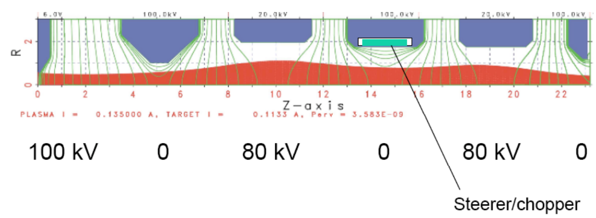

FIGURE 5. 113-mA proton LEBT (half section, distances given in cm).

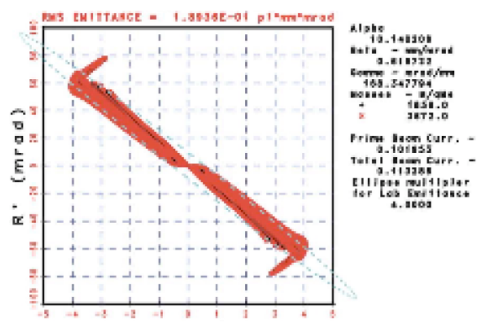

FIGURE 6. Simulated r/r' emittance of 0.19 π mm mrad rms size, for the LEBT shown in Fig. 5.

Due to the higher beam current and resulting beam blow-up, the effects of aberrations are slightly more pronounced for this second LEBT than those seen in Fig. 4 but still much less severe than found with the SNS LEBT. Typically, rms emittance sizes of 0.2 π mm mrad are well compatible with Proton Driver Linac acceptances, and the design can certainly be improved by making the components wider and longer.

The action of the steerer plates integrated into this LEBT has been investigated by performing 2-d simulations in the x/y mode of PBGUNS, assuming infinite extension orthogonally to the steering action. The resulting steering angles and transverse offsets as a function of plate voltages are shown in Fig. 7.

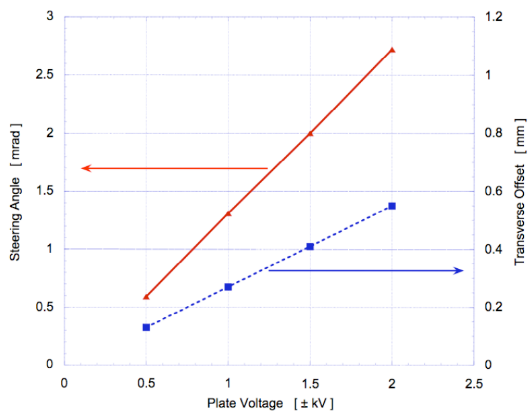

FIGURE 7. Steering angles (red) and transverse offsets as a function of applied plate voltages for the LEBT shown in Fig. 5.

EXTRACTION SYSTEM FOR H$^-$ IONS

For H- beams, the removal of extracted electrons from the beam is a key issue that affects beam quality as well as ease of operation and reliability. A novel extraction system design, inspired by previous work of a different group [6], has been developed where electrons and H$^-$ ions are extracted together by a two-gap structure and the electrons are deflected by a dipole magnet and deposited on the center electrode at intermediate energy, see Fig. 8. The minor kick given to the ions by this dipole field is compensated by a second dipole magnet of about twice the integrated field strength, placed on the main extractor electrode on ground potential. The ion beam leaving this system runs parallel to the original system axis, with a slight transverse offset.

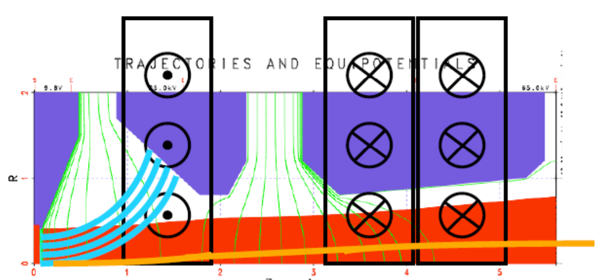

FIGURE 8. Two-gap extraction system for a 60-mA H$^-$ beam; R and Z units in cm. The electrode potentials are, from left to right, 65, 40, and 0 kV, respectively. The ion trajectory plot (full red) results from the simulation of a magnet-free system. The plot has been overlaid by the shapes of the dipole magnets, schematic electron trajectories (blue lines), and the schematic ion beam centroids (orange line).

The emittance resulting from the magnetic field-free simulation is given in Fig. 9, and Fig. 10 shows results of analytical calculations that illustrate the deflecting effects of the applied transverse magnet fields on electron and ion trajectories.

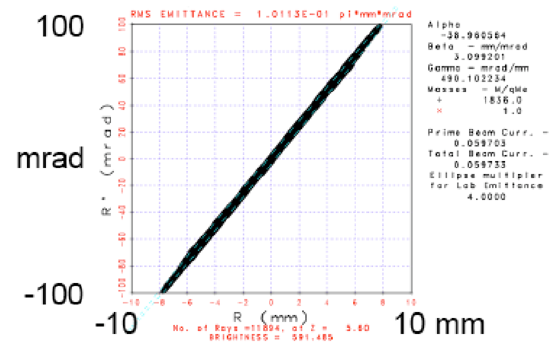

FIGURE 9. Emittance of the two-gap extraction system shown in Fig. 7, based on the magnet-free simulation. The normalized r/r' emittance has a size of 0.1 π mm mrad.

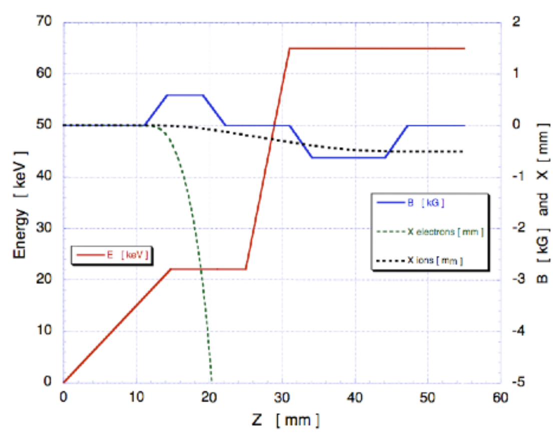

FIGURE 10. Plot of analytical calculations illustrating the effect of anti-parallel transverse magnet fields (blue trace) on electron (green dotted line) and ion (black dotted line) trajectories. Particle energies are indicated schematically by the red line (left scale).

As seen in Fig. 10, the ion beam leaves the extraction system parallel to the axis, with a transverse offset of about 0.5 mm. To assure this parallelism in praxi, one has to fine-tune the integrated field strength of at least one of the dipole magnets. This could be achieved by installing electromagnets or by adjusting the gap width of a pair of permanent magnets. The axis of the adjacent LEBT structure still has to be aligned to the shifted beam axis, but a fixed alignment will be sufficient if steerer plates are included in this LEBT.

Even though the simulation and calculation results presented for the two-gap extraction system are not self consistent they clearly indicate the potential of such a layout. The main benefits of this design approach are seen in the reduced space charge density created by the electrons as compared to the SNS extraction system, together with the elimination of the 3-degree axis tilt that leads to asymmetric electrical fields.

CONCLUSIONS

The new design approach to electrostatic LEBTs and H^- extraction systems presented here is based on 2-d simulations whose validity has been demonstrated in a number of cases [2]. The envisaged benefits in terms of reduced emittance sizes and operational advantages should warrant pursuing these design ideas in more elaborate, self consistent 3-d simulations and by experimental tests.

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